COORDINATION OF PROTECTION AND ACTIVE NETWORK MANAGEMENT FOR SMART DISTRIBUTION NETWORKS

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ABSTRACT

Future energy networks are expected to be flexible and accessible entities that will result in highly efficient and reliable power delivery, with open access to network participants and optimal utilisation and management of assets. Research in protection and active network management (ANM) has independently developed novel solutions to meet the requirements of future networks. The existing and proposed solutions generally decouple ANM and protection systems; however under certain circumstances, such arrangements may render each independent system vulnerable to incorrect operation due to the nature of the other's operation. This paper discusses independently developed ANM and adaptive protection solutions and describes situations where it is beneficial to couple the ANM and protection systems. The paper illustrates, using a typical 11kV case study network, how including inter-communication between ANM and protection solutions can be beneficial and in some cases essential to allow more efficient operation of the ANM and protection solutions. Scenarios are examined for normal system operating conditions and islanded operation. Conclusions are drawn from these scenarios highlighting the identified requirements of a coordinated scheme.

INTRODUCTION

The on-going increase in the penetration of distributed generation (DG) has entailed the development of new solutions for the protection and operation of distribution networks. New protection solutions are essential in order to avoid mal-operation of the protection system and minimise unnecessary disconnection of DG units. In addition, new ANM tools are required to manage emerging operational technical constraints associated with parameters such as voltage and thermal limits, and manage incentivised commercial requirements such as automatic restoration and minimisation of power losses.

The introduction of DG on to the distribution network impacts upon power flows, voltage conditions and fault current levels. These impacts can be positive, such as reduction of voltages sags [1] and release of additional network capacity [2], but can negatively impact on the protection systems. DG introduces additional sources of fault current, which may increase the total fault level within the network, while possibly altering the magnitude and direction of fault currents measured by the protection systems. The contribution of one single DG is normally relatively insignificant, but the aggregate contribution of many DG units can lead to a number of problems such as: blinding, false tripping and loss of grading[2].

An attractive solution to these protection problems is the use of an adaptive protection system, which as defined by the IEEE in [3], is "a protection philosophy that permits and seeks to make adjustments automatically in various protection functions to make them more attuned to prevailing power system conditions".

Individual constraint management systems for new DG connections are normally integrated to ensure that network security is preserved. To date, this often results in multiple bespoke schemes operating independently for single DG connections based upon the particular constraint(s) that the connection requires. The growth of DG connections increases the number of management schemes and can add complexity to the operation and control of the network.

A possible solution is the adoption of active network management (ANM) schemes, which are often real-time monitoring and control strategies adopted to facilitate increased DG connections, while avoiding high network reinforcement costs, or at least, reducing or deferring reinforcement capital expenditure [4].

Protection and ANM solutions are normally viewed independently. Traditional distribution network overcurrent protection systems are designed to trip for faults or overloads without considering the presence of ANM schemes. From the ANM perspective, such solutions generally focus on managing system constraints under 'normal' network conditions, where protection solutions are viewed as the 'last line of defence'.

ADAPTIVE OVERCURRENT PROTECTION

To allow higher levels of DG penetration, adaptive overcurrent protection has the potential to solve protection issues arising from DG; and to properly cater for ANM solutions, which may change network topology. In addition, adaptive overcurrent protection can decrease the overall operating time of the protection system which reduces the duration of voltages sags in the network during faults, consequently reducing the possibility of unnecessary disconnection of DG during faults in adjacent feeders.

Adoption of adaptive overcurrent protection can also avoid loss of grading when the network configuration is changed, for example to restore supply to loads.

An adaptive overcurrent protection system has been developed and demonstrated at the University of Strathclyde using a real time simulator with actual protection relay hardware in the loop, shown in Figure 1.

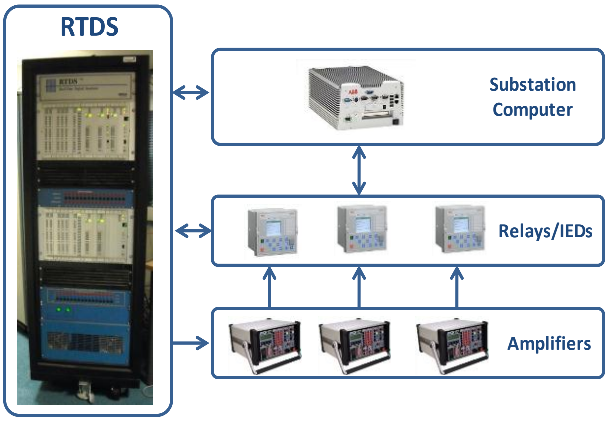

Figure 1 - Hardware in the loop testing environment

The developed scheme is capable of monitoring a distribution network simulated in the RTDS using an actual SCADA system to detect changes in the network, such as topology modifications and DG trimming and tripping. It then uses the acquired network data to run fault analysis calculations, determine and apply optimum protection settings to the protection relays using IEC 61850 communication. This testing environment is a very high-fidelity platform and therefore an accurate emulation of real-world network and secondary system arrangements can be achieved.

ACTIVE NETWORK MANAGEMENT

Facilitating increased DG connections through use of ANM has been demonstrated to have the potential of increasing energy sourced from renewable generation and also to manage the economics associated with DG [5].

Adoption of ANM can avoid the lengthy process of reinforcement planning applications by enabling DG units to utilise the existing network capacity headroom. Since inception, ANM has evolved to include functionality to manage distribution network constraints in real-time. This includes the control of all 'active' devices from generators through to demand side functions such as voltage control, power flow management, automatic restoration and minimisation of power system losses.

ANM functionality and architectures have been developed and demonstrated at Strathclyde [6]. The developed ANM functionality, which includes power flow management [7-9], voltage control [10] and loss minimisation [11] algorithms, have been demonstrated and tested using the arrangement shown in Figure 1.

TEST CASE NETWORK

The scenarios used to investigate operation of coordinated adaptive protection and ANM is based on a typical UK 11kV distribution network model, with data supplied from utility partners, as shown in Figure 2.

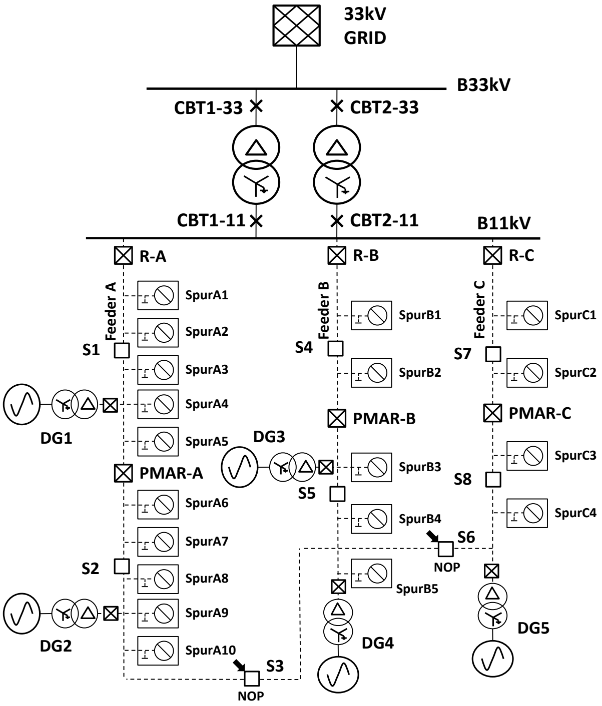

Figure 2 - Test case network

The ANM scheme may have the capability to change the network topology and transfer load or DG to different feeders or substation by operating network switches, such as S1-S8 in Figure 2. In addition, the ANM scheme may initiate control actions to trim and/or trip DG units (DG1-5) for the purposes of voltage control, power flow management and loss minimisation.

The adaptive overcurrent protection system monitors the power system using a SCADA system and when there is a change of network topology or DG connection, it amends the protection settings in real time to optimise the performance of the overcurrent protection system.

COORDINATION OF PROTECTION AND ANM DURING NORMAL OPERATION

During normal operation, when the distribution network is connected to the main grid, there are a number of scenarios where coordination between ANM and protection schemes is beneficial.

Scenario 1

The ANM system changes the network topology and the adaptive overcurrent protection system adapts the protection settings of the overcurrent protection relays

(OCRs) to the new network configuration. For example, considering Figure 2, the ANM changes the network topology by shifting the NOP from S3 to S1, and the adaptive protection system adapts the protection settings of the OCRs to avoid mis-coordination between PMAR-A and PMAR-B.

In this scenario the operation of the ANM system can cause unwanted tripping of the protection system before the adaptive protection system changes the protection settings, therefore a better coordination method is necessary.

A possible solution to this issue is that the ANM interrogates the adaptive protection system controller prior to taking action to verify that the proposed action will not cause unwanted tripping. If that is the case, the adaptive protection system can change the protection settings just before the ANM action to the modified protection settings or to momentary protection settings with lower protection sensitivity while the topology is changed.

This solution would overcome the problem of unnecessary protection operations and ensure that customer minutes lost (CML) and customer interruptions (CIs) are reduced.

Scenario 2

When there is a fault in the network, for example downstream of PMAR-B in Figure 2, the PMAR detects the fault and opens to clear the fault, then it attempts to reclose two or three times, and if the fault is permanent it locks out.

In this scenario, the ANM scheme should be informed of PMAR-B's initial trip event to ensure that ANM services are postponed such that solutions are not generated during transient conditions. When PMAR-B's protection cycles are completed and the position of the PMAR-B is know this needs to be communicated to the ANM scheme. If PMAR-B is locked out, then an update of network topology is required. Conversely, if PMAR-B successfully recloses, the ANM can continue with normal service.

Furthermore, in this scenario DG3 would be disconnected on loss of mains after the first PMAR-B operation, thus removing a controllable device from the ANM scheme. The ANM scheme would require data relating to PMAR-B's final state to enable the inclusion or exclusion of DG3 in future management decisions.

In this scenario, informing the ANM scheme of the overcurrent protection system operation is beneficial in terms of being able to postpone and resume normal ANM services.

Scenario 3

When there is a particular network constraint (power flow or voltage), the ANM system can issue control changes to regulate the DG power output (e.g. trimming and/or tripping). When calculating any set-point change, the ANM scheme would normally consider the static summer/winter ratings or dynamic line ratings.

For example, considering Figure 2, the ANM can reduce DG1 power output to maintain busbar voltages within statutory limits or to manage the power flows on Feeder A. In this scenario, if an adaptive overcurrent protection system is in operation, the action to reduce DG1's output may cause overload tripping of the circuit breaker R-A, depending on the present protection settings applied to R-A to optimise the overall protection system performance.

To overcome this problem, it is necessary that the ANM and the adaptive overcurrent protection system are coupled. A possible solution is that the adaptive overcurrent protection system informs the ANM scheme about the permissible maximum load for each protection device before tripping will occur. The ANM system therefore must base its decision on the present protection settings or make a request (to the adaptive over current scheme) to increase a particular protection device's pick-up current setting if feasible. It may therefore be necessary to include an operating margin within the ANM scheme to ensure that protection devices will not mal-operate.

In this scenario, the advantage of coupling ANM and adaptive protection would be to allow the benefits of both solutions and to avoid any ANM actions to cause mal-operation of the protection system and vice-versa.

COORDINATION OF PROTECTION AND ANM DURING ISLANDED OPERATION

Present utility practice is normally to prohibit islanded operation of distribution networks, with only a few exceptions. This means that when islanded operation is detected, all relevant DG units are normally disconnected by LOM protection [12].

However, with the increasing penetration of DG, islanded operation of parts of the network might become more attractive, particularly in areas that are geographically isolated from the rest of the network and where allowing islanding operation would have the advantage of reducing CML and CIs.

Islanded operation can be a proactively planned action, or a post-fault reactive action. In both cases, the LOM protection relays of the DG units in the power island must not disconnect the generation during the change from grid connected to islanded operation.

One possible solution to avoid mal-operation of the LOM protection relays, when the islanded operation is a planned action, would be to relax the protection settings of the LOM during the change from grid connected to islanded operation.

Islanded operation can be also a post fault occurrence where the LOM protection system detects the islanding operation and, instead of tripping the DG units, informs the ANM to take the necessary action to control the DG units and the loads to maintain voltage and frequency within statutory limits.

One of the technical challenges in this scenario is that the

LOM protection should decide between tripping the DG units or allowing islanded operation based on its protection settings. It cannot wait to interrogate the ANM about the feasibility of islanded operation as that would introduce an unnecessary, and potentially hazardous, delay.

A solution to this problem could be that the ANM evaluates continuously whether islanded operation would be feasible and informs the LOM protection system, which would then adapt settings as necessary.

Another approach to islanded operation is to let the LOM protection disconnect all DG units. Then, the ANM evaluates the possibility of islanded operation of that sub-network, and if that is possible it would reconnect all the DG and loads incrementally to restore power to sub-network island.

Finally, another protection issue related to islanded operation of a network is that the fault level is usually much lower than when operating in grid-connected mode; therefore it is usually necessary to adapt protection settings. To facilitate this, the ANM could inform the adaptive overcurrent protection system about the new state of the network or the intention to switch to islanded operation so that settings could be modified appropriately.

CONCLUSIONS AND FUTURE WORK

This paper has illustrated that traditionally ANM and adaptive protection solutions are developed and successfully operated independently. However, in order to realize the smart grid vision, more research is required to understand the level of ANM and protection function coupling to ensure flexible and efficient operation is achieved.

A number of scenarios have been described, above, where it is shown that evolving protection and ANM schemes would operate more effectively if a coordinated approach of the schemes was adopted. To enable ANM schemes to manage distribution networks outwith normal operating conditions it is crucial that the scheme has visibility of what protection devices are in operation, the device settings and device status. In addition, for adaptive protection schemes to calculate efficient and effective settings the control actions of an ANM system impacting upon these settings must be known and taken into consideration. In some circumstances it would be necessary for one scheme to interrogate the other in order that detrimental actions are not issued and therefore would not contribute to increased supply interruptions.

Future research and developments will entail refining, operating and coupling the independently developed ANM and protection functions on laboratory hardware in the loop. In order to harmonise management and protection functionality a secure and reliable communications infrastructure is fundamental. Subsequent research would therefore be required to establish the negative impact of communication failures and latencies in a bid to create fallback positions. Further demonstration and testing of the coordinated scheme in an operational environment, at the University’s Power Network Demonstration Centre, can deliver the required levels of confidence needed to adopt such schemes.

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